The structure of Fe–Si soft magnetic alloys with induced anisotropy of magnetic properties

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I. Introduction

When of need to meet the requirements of a special application, soft magnetic properties of the crystalline and nanocrystalline Fe–Si alloys can be modified by means of inducing magnetic anisotropy in the course of magnetic-field (MFA) or tensile-stress (TSA) annealings. Thus, in the crystalline α-FeSi alloys with low (2-14 at.%) silicon content a uniaxial magnetic anisotropy is induced via dc MFA or via TSA [1]. Measured in the direction of magnetic anisotropy, the intensity of magnetic losses and the value of the coercive force exhibit a decrease, whereas residual magnetization increases, as well as magnetic susceptibility. A domain structure with arising magnetic anisotropy also undergoes changes, its pattern alters; it can become stabilized (after TSA or dc MFA) or destabilized (after MFA in a rotated or an ac magnetic field).

Tape samples of nanocrystalline $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ alloy (finemet) [2] possess record-low both coercive force ($0.5\cdot10^{-4}$A/m) and remagnetization losses, as well as high residual magnetization and permeability (up to 10^5). Upon TSA, with the direction of loading along the tape axis, a transverse anisotropy of magnetic properties is induced [3]. The hysteresis loop acquires the shape of straight slanting line – up to saturation field, whose value depends on the magnitude of applied load under TSA and amounts to H_s = $1.5\cdot10^4$A/m, with magnetic permeability remaining invariable within from $-H_s$ to H_s.

II. Experimental results and discussion

The atomic structure of the α-$Fe_{1-x}Si_x$ (x = 0.05÷0.10) single crystals possessed of capability to undergo induction formation of a uniaxial magnetic anisotropy was studied using methods of X-ray diffraction analysis. It has been found that their local atomic structure is characterized by chemical short-range ordering of *B*2-type in combination with a certain order in the displacements of atoms from the sites of an ideal crystal lattice. The pairs of *B*2 unit cells oriented along the easy magnetization axes <100> and the tensile-distorted cells of *bcc* lattice surrounding them form anisotropic local distribution of atoms – the anisotropic *B*2 clusters. Upon annealing in a dc saturating magnetic field or under stress loading, anisotropic *B*2 clusters are oriented mainly along one of the easy axes, namely, that one which makes a minimum angle with the direction of external loading. After cooling, the structure formed becomes "frozen", which provides for the appearance and stability of the uniaxial anisotropy of bulk magnetic properties. In $Fe_{0.92}Si_{0.08}$ and $Fe_{0.90}Si_{0.10}$, the *B*2 clusters coexist with clusters of $D0_3$ phase, the latter being isotropic. With increasing x, the increase in the $D0_3$-phase amount progressively suppresses the magnetic anisotropy caused by anisotropic distribution of *B*2 clusters, and, to be exact, completely, at x ~ 0.14.

After annealing under tensile loading of finemet alloy $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, the interplanar spacings in the *bcc* lattice of Fe–Si nanocrystals increase – in the tensile stress direction (TSD) – and decrease, in the transverse direction. Being of high rigidity, the amorphous matrix, which "envelops" the nanocrystals, hampers a relaxation of their distorted structure. The lattice is deformed not isotropically. It turns out that the value of a change in the spacing Δd_{hkl} between the planes (*hkl*) depends on the angle between the direction of the wave vector [*hkl*], when it is parallel to TSD, and the nearest axis <111>. The greater is this angle, the larger the deformation: Δd_{111} has a minimum value; in the direction of easy magnetization [100], Δd_{100} is maximum. More than half the volume of the nanocrystals is occupied by the phase Fe_3Si ($D0_3$), whose crystal lattice after TSA has the same character of strain. Since the nanocrystals with a constituent composition close to Fe_3Si stoicheometry have a negative value of magnetostriction, then at tension along the axis [100] which makes a minimum angle with TSD, – a magnetization is induced in the plane normal to the axis of loading, namely, along one of the easy axes [010] or [001]. Since the number of nanocrystallites is very high and their distribution is isotropic, then a great deal of the crystallites stretched along the ribbon contribute to a transverse distribution of magnetization in the plane that is transverse to TSD.

III. Conclusion

Investigations of the structure of the soft magnetic crystalline α-FeSi and nanocrystalline (finemet) alloys have shown that the magnetic properties are closely connected with the atomic structure formed in the process of magnetic-field or stress-related treatment.

This work was supported by RFBR, grant no. 09-02-00134.

References

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